COVER SHEET

U.S. PATENT APPLICATION
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APPLICATION NO. 60/392,369)

ENTITLED:
EXCAVATOR TEETH, APPARATUS AND METHODS

ASSIGNEE:
PENNSYLVANIA CRUSHER CORPORATION
BROOMALL, PENNSYLVANIA

INVENTOR:
WAYNE A. WAGNER

INVENTOR'S RESIDENCE:
463 Alaho Street
Akron, OH 44305

ATTORNEYS:
ROBERT R. PRIDDY
MATTHEW A. PEQUIGNOT
HALL, PRIDDY, MYERS & VANDE SANDE
10220 RIVER ROAD, SUITE 200
POTOMAC, MARYLAND, 20854
PHONE: 301-983-2500
FAX: 301 983 2100

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EXCAVATOR TEETH, APPARATUS AND METHODS

RELATED APPLICATION DATA

This application depends for priority on U.S. Provisional Patent Application No. 60/392,369, filed July 1, 2002.

TECHNICAL FIELD

The invention relates to teeth useful in connection with excavating machines, and to digging implements and excavating machines comprising such teeth.

BACKGROUND

The teeth commonly employed on digging implements for excavation machines, such as for bucket leading-edges, ripping arms and dredge-heads, have a limited service life, depending in part upon the severity of the abrasion to which they are subjected. Severe applications include rock fracturing and removal, and excavation of frozen earth. In a rock trenching operation in Ohio, U.S.A. sandstone with a very powerful excavating machine having a digging implement equipped with cast high abrasion resistance alloy teeth, service lives as low as less than an hour were experienced. This invention seeks to fulfill a need for improved excavator teeth and excavation methods.

SUMMARY OF THE INVENTION

In one aspect, the invention relates to an excavator tooth useful for fracturing rock strata. It comprises a metallic core having front and rear ends and at least one longitudinal surface extending between said ends. There is also at least one projection formed from metallic stock, which may for example be bar stock of round, square or rectangular cross-section, or more preferably may be plate stock. A projection according to the invention has a tip, which is an end of the projection, of whatever shape, that is intended to act on the rock or other material on which the tooth may be used. Such projection is secured to the core, at least in part by welding, with the tip and at least portions of the length of the projection(s) extending beyond the front end of the core. In or on the core there is at least one tooth connector portion, including at least one concave or convex connector surface, of circular or other configuration, positioned and adapted to

engage with and non-destructively disengage from at least one mating surface of an excavator apparatus.

The invention has a variety of additional aspects, among which are preferred and highly preferred embodiments. For example, the core may be of circular or non-circular cross-section, and may have a single longitudinal surface in the form of a cylinder or plural longitudinal surfaces.

The at least one projection preferably includes at least one cut edge, an edge formed at least in part in cutting the projection from the metallic stock, and this edge may for example be an end of the projection when it is cut to length from bar stock. More preferably, the cut edge is a longitudinal edge, for example an edge resulting from cutting the projection from a plate.

It is preferred that the projection metallic stock thickness be about 1/2 to about 3, or about 3/4 to about 2 and 1/4 or about 1 to about 1 and 1/2, inches. This dimension will correspond, for example, to the diameter of round bar stock or the thickness of plate stock.

In a particularly preferred embodiment, the tooth includes at least one projection which has on opposite sides thereof, as viewed in transverse cross-section, at least two approximately planar surfaces which are approximately parallel to one another. Preferably, these surfaces of the projections are approximately parallel to the digging direction of the tooth. More preferably, when viewed in transverse cross-section and when positioned vertically in the view, these surfaces are at least about as tall as the distance between them.

Preferably, there are at least two projections on the excavator tooth. More preferably, these are secured to substantially opposite sides of the core.

In a particularly preferred embodiment, there are at least two projections that have inner surfaces, portions of which surfaces generally face one another and extend forwardly from the core. These portions, as they progress toward their tips, have an angle of divergence between them of about 0 (i.e., no divergence or a small convergence) to about 30 degrees,

preferably about 2 to about 30 degrees, more preferably about 12 to about 24 degrees, still more preferably about 16 to about 20 degrees and most preferably about 18 degrees.

In another aspect, the projection metallic stock is preferably of abrasion resistant steel having a surface BHN (Brinell Hardness Number) of at least about 225, more preferably at least about 300, more preferably at least about 350, more preferably at least about 375 and more preferably at least about 400, at least prior to its fabrication into teeth according to the invention, and more preferably after such fabrication.

Preferred embodiments of the projection metallic stock comprise iron, carbon, manganese and silicon, and optionally but preferably at least one additional alloying element selected from the group consisting of chromium, nickel, boron, molybdenum, vanadium, titanium, copper, aluminum, niobium and nitrogen. More preferably,the sulfur and phosphorous contents of the metallic stock are respectively less than about 0.05, preferably less than about 0.04 and still more preferably less than about 0.030 percent by weight of the entire stock.

In a preferred embodiment, there is a narrowing of at least one projection, between its generally longitudinal edges, in the direction of the tip, which may for example occur along a single edge.

However, in still more preferred embodiments, first and second longitudinal edges of at least one projection, or more preferably first and second edges of a plurality of projections, converge with one another, along at least a portion of their respective lengths, in the direction of their tip or tips.

In a particularly preferred embodiment, such narrowing, or such convergence, exists at least closely adjacent to the tip or tips.

Most preferably, the projection edges converge, as the edges approach the tips, preferably at an angle of about 10 to about 35 degrees, more preferably about 15 to about 30 degrees, still more preferably about 17 to about 25 degrees and even more preferably about 21±2 degrees.

A particularly preferred form of the invention comprises convergence of at least portions of projection longitudinal edges along substantially straight lines, preferably closely adjacent to their tip or tips.

Preferably, convergence occurs over at least about 25% and more preferably up to at least about 100% of the length of the projection longitudinal edges

Preferably, the projection or projections respectively include two convergent edges that are cut edges.

It is preferred that at least one projection be secured to the core through at least one longitudinal surface of the core. Advantageously, the projection or projections is/are secured to the core preferably entirely, by welds. In a particularly preferred embodiment, said at least one longitudinal surface has a plurality of projections secured thereto at least in part by welds between the at least one surface and adjacent portions of the projections.

The tooth connector portion may be located at the rear end of the core, preferably in or on a rearmost surface of the core.

Wherever located on the core, the tooth connector portion may be securely connected with a mating surface of an excavator apparatus. In a preferred embodiment, the tooth connector portion is a female member extending into the rear end of the core and the mating surface is a male member on an excavator apparatus, or vice versa.

A locking member may be present, e.g., a resilient insert or metallic pin, to engage the tooth and a portion of the excavator apparatus, thus providing security for the connection between the tooth connector portion and the mating surface.

According to the invention, the excavator apparatus may be any excavating machine adapted to carry, in working position, one or more teeth constructed according to the invention. Such excavator apparatus may for example be an excavating machine selected from the group consisting of

power shovels, backhoes, draglines, dredges, graders and bulldozers, or may be a digging attachment or combination of attachments adapted to be mounted on an excavating machine and to carry, in working position, one or more of said teeth.

In one particular embodiment, the excavator tooth is connected with a bucket having a mounting pin for connecting the bucket to an excavating machine. The tooth has a projection with a major surface which is held in approximately perpendicular relationship with the longitudinal axis of the mounting pin.

Another embodiment includes an excavator tooth connected with a rock ripping tool having a mounting pin for connecting the tool to an excavating machine. Here, the tooth has a projection with a major surface which is held in approximately perpendicular relationship with the longitudinal axis of the mounting pin.

Still another embodiment comprises an excavator tooth connected with a bucket or blade at a substantially rectilinear cutting edge of the bucket or blade. That edge is or has a digging axis, and a major surface of the tooth is held in approximately perpendicular relationship with that axis. On the other hand, the bucket or blade may have an at least partly non-rectilinear cutting edge having ends at sides of the bucket or blade. In which case, an imaginary line connecting those ends defines the axis.

In yet another embodiment, an excavator tooth is connected with digging end of a pivotable ripping arm for an excavating machine. This arm has a pivoting axis about which the arm swings in operation. A major surface of the tooth is held in approximately perpendicular relationship with the axis.

Other aspects of the invention includes methods of excavation. Among these are a method of excavation with an excavating machine having an arm with a pivot affording angular movement of an end of the arm about a central axis of the pivot, said arm supporting and delivering digging force and motion to a digging implement having projections. This method comprises applying such force through projections that are formed of cut

plate stock and have major surfaces that are approximately perpendicular to said axis.

The invention also includes a method of fracturing rock or frozen earth with an excavating machine having an arm with a pivot affording angular movement of an end of the arm about a central axis of the pivot, said arm supporting and delivering digging force and motion to a digging implement able to apply sufficient force through the tips of projections on said implement to break up the strata. This method comprises applying such force through projections that are formed of cut plate stock and have major surfaces that are approximately perpendicular to said axis.

Optional but preferred embodiments of each of the foregoing methods include applying such force through teeth having edges that converge at angles as above described, and/or applying such force through teeth respectively having two projections with inner major surfaces generally facing one another and having an angle of divergence between them as above described. Still other optional but preferred embodiments of each of the foregoing methods comprise applying such force through teeth wherein the plate stock is abrasion resistant steel plate having a surface BHN as above described and/or having a composition as above described.

Other embodiments of the invention are described below, and additional embodiments of the present invention, not disclosed herein, can be constructed by persons skilled in the art without departing from the spirit of the invention.

ADVANTAGES

This invention makes available improvements in excavator teeth. Most embodiments of the invention will include one or more of the following advantages. Certain preferred embodiments will include all of these advantages. As compared to common, cast, replaceable steel teeth used in the past, it is possible for persons skilled in the art of steel fabrication to fabricate excavator teeth according to the invention which exhibit excellent cutting properties, long life in rock excavation and other applications,

reduced cost for teeth per hour of operation and ease of fabrication. One can fabricate embodiments that afford a strategic balance between service life and ease of penetration of rocky strata. Moreover, the invention offers the possibility of providing a range of satisfactory products which offer a degree of flexibility with respect to this balance. Where the projections have approximately parallel sides, then, for a given cutting edge width, the invention provides improved bending resistance in the projections, as compared with teeth having projections formed from round bar stock. The methods of the invention offer the operational advantages set forth above. Other advantages of these excavator teeth and methods will become apparent to those skilled in the art upon using the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side view of an excavator tooth according to the invention.

Figure 2 is a top view of the excavator tooth of figure 1.

Figure 3 is a view, in perspective, of another embodiment of the invention having a core which is the remnant of a cast excavator tooth from which the original teeth have been worn away.

Figure 4 is a side view, partially in section, of yet another embodiment of the invention having two projections, a portion of a projection in the foreground being broken out to reveal a projection in the background and parts between them.

Figure 5 is a perspective view of still another embodiment of the invention.

Figure 6 is a side view, partially in section, of the embodiment of figure 5, but with the addition, in phantom outline, of a portion of an excavator apparatus.

Figure 7 is a perspective view of a digging implement, i.e., a ripping arm, having mounted on its end an excavator tooth as a shown in figures 1 and 2.

Figure 8 is a perspective view of a digging implement having thereon a ripping arm and excavator tooth as shown in figure 7.

Figure 9 is a perspective view of a digging implement having thereon two ripping arms, respectively having excavator teeth as shown in figure 7.

Figure 10 is an end view, with portions broken out, of a dredge cutter-head.

Figure 11 is a perspective view of a digging implement, i.e., a bucket, having a rectilinear front edge provided with a row of excavator teeth according to the invention.

Figure 12 is a perspective view of a digging implement, i.e., a bucket, having a non-rectilinear front edge provided with adapters and with excavator teeth according to the invention, two of five teeth being left off of their adapters to simplify the view.

Figure 13 is a side view of a backhoe unit including a ripping arm equipped with one or more excavator teeth according to the invention.

Figure 14 is a side view of a power shovel including a ripping arm equipped with at least one excavator tooth according to the invention.

Figure 15 is a side view of a dragline unit including a bucket having excavator teeth according to the invention.

Figure 16 is an enlarged portion of figure 15 providing greater detail with respect to the bucket.

VARIOUS AND PREFERRED EMBODIMENTS

Cores may be formed of any suitable metal. Preferably, the metal of the core should be readily weldable, economical and of adequate durability, for example, crack resistant, ductile, reasonably hard, strong and tough. In general, such metal will be chosen from among one or more alloys including one or more alloying elements to promote one or more of the properties of wear resistance and fracture resistance, more preferably

alloys that contain iron as a major component (more than 50%) by weight. The cores may have and preferably do have less wear resistance than the projection(s). Wear resistence should be sufficient to maintain, in rock excavating service, the structural integrity required to securely support the excavating projection(s) and perform their connecting function over the useful life of the projection(s).

Fracture resistance should be sufficient to resist breakage of the core under the loads imposed in rock excavating service. Rock excavating service includes, for example, one or to more of the following: use on buckets or other digging implements attached to the arms of backhoes engaged in digging rocky soil or gravel; more preferably, use on drag-line buckets engaged in the stripping of frozen earth and/or rocky overburden; and, most preferably, service on buckets or other digging implements attached to the arms of large and very powerful hydraulic shovels, for example, Caterpillar model 385, engaged in the fracturing and subsequent removal, e.g., digging, of rock strata. The fracture resistance requirement depends on loads which are sustained in operation, which to some degree depend on force exerted by excavating machine, the hardness of the rock to be penetrated by the tooth and leverage imposed on the core by the design of the tooth, for example leverage imposed by the lengths of the core and the projection(s).

Temper resistance can also be a beneficial property, such as when it assists in warding off to some extent loss in hardness arising out of heating of the core during welding of the projections to the core or during frictional engagement with rock when the tooth is in use.

One example of suitable metals for the core is carbon steel conforming to ASTM Standard A-27, preferably grade 70-36. Because of their low cost and ease of welding, these are considered best for applications in which the core will not be subjected to heavy abrasion, such as where only softer rock is to be fractured and or the projections extend far beyond the fronts of the cores. Where greater abrasion resistance is needed, it is considered best to use cast steels conforming to AISI 8630 or ASTM A148, preferably grade 90-60, either of which type of material has been quenched and

tempered to any suitable hardness level, for example a BHN of about 300 to about 400. Other suitable core metals include, for example, the remnants of worn, cast rock fracturing teeth, such as those manufactured by Hensley and others.

Approximate compositions of a number of these core metals, by weight, the balance being iron, appear below:

Metal	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	Al
90-60	.32	1.5	.05	.05	.45			.4			
8630	.3	.8	.03	.03	.23	.5	.55	.2			
Hensley	.28	.64	.02	.01	1.2	1.7	.2	.4	.04	.02	.03
Other	.31	1	.02	.01	1.2	2	.05	.45	.02	.01	.01

The specific examples of metals set forth above appear sufficient in fracture resistance and temper resistance and the other properties enumerated herein for purposes of making cores. However, it is believed that there is a wide variety of other suitable metals and that persons skilled in the metallurgical arts are able to adust metals composition and heat treatments applied to such other metals to achieve desired levels of weldability and durability to produce acceptable cores. For further guidance on effecting desired levels of hardness, fracture resistance, temper resitance and other beneficial properties, see U.S. Patents 5,525,167 and 5,595,614 and other patents identified therein, the disclosures of all such patents being incorporated herein by reference in their entireties.

Cores may be formed as one or more castings (single casting preferred) or as a fabricated assembly of segments of plate or non-plate components or in any other suitable way from any suitable new (virgin or used metal not previously employed as a tooth core) or used (previously used as a portion of a tooth) material. Examples of used materials include the remaining shanks of tooth from which the projections have been worn away. Used

cores are not preferred, due to expectation of undependable supply. However, used cores, where available, can be made into teeth better than the originals.

Preferred embodiments of cores have front ends that include front surfaces of any workable shape, rear ends with any shape consistent with the connector function, described below and a longitudinal axis. The longitudinal surface(s) of the core may have a surface or surfaces of any number or shape, including one (e.g., cylindrical) and plural (e.g., three or more) (four preferred). As viewed in transverse cross-section, the core's exterior surface may be of any shape, symmetric or asymmetric, for example, may be at least partly circular, oval, triangular, square, rectangular, diamond, polygonal, parallelogram, trapezoidal, modifications of any of the foregoing, composite shapes (combinations of the above), e.g. generally square but with rounded corners. Such cross-section may be uniform or variable along its length, but is preferably flattened on two sides where two projections are welded to it. The longitudinal cross-section of the core's exterior surface may have any suitable shape, may be uniform or variable along its length, may be tapered, at least in part (preferred), may have divergent "land(s)" on which to weld divergent projection(s), when divergent projections are used and may be non-tapered.

Teeth fabricated according to the invention have one or more projection(s) which may for example be fabricated from metallic stock, such as bar stock, but preferably from plate stock. The metallic stock has a composition and/or treatment history contributing to the presence, in the stock, of properties of wear resistance, fracture resistance and temper resistance sufficient for satisfactory fabrication of and service in excavating teeth.

Preferably the metallic stock is abrasion resistant steel, having a composition and treatment history being sufficient to provide in the stock a surface BHN (Brinell Hardness Number) of at least about 225. Still more preferably, the metallic stock is an abrasion resistant quenched and tempered steel alloy which comprises iron, carbon, manganese and silicon, and optionally but preferably at least one additional alloying element selected from the group consisting of chromium, nickel, boron,

molybdenum, vanadium, titanium, copper, aluminum, niobium and nitrogen, the amounts of the aforementioned constituents and the treatment history of the stock being sufficient to provide in the stock a surface BHN of at least about 300, more preferably at least about 350, still more preferably at least about 375 and most preferably at least about 400. Most preferably, the sulfur and phosphorous contents of the stock are respectively less than about 0.05, preferably less than about 0.04 and still more preferably less than about 0.030 percent by weight of the entire metallic stock.

Preferably, the wear resistence, fracture resistance and temper resistance of the projection metallic stock and resultant projections are sufficient for the projections to remain useful for fracturing rock, while avoiding major breakage of the projections and retaining at least about 50, at least about 70 or at least about 85% of their as-manufactured hardness, in rock excavating service, over a period of at least about 4, more preferably at least about 8, and still more preferably at least about 16 and most preferably at least about 40, hours of operation. In some instances, where a particular projection of very hard metal tends to be quite brittle, a workable tooth may be manufactured by using metallic stock having less hardness.

Suitable metals are available, including for example USS (United States Steel) AR 225, AR 350, AR 400 and AR 500, USS T-1 and USS T-1, types A, B and C, and USS Ni-Cr-Mo; Lukens Hardwear (tm) 235, 400, 425 and 500; Bethlehem AR 235, RQC, RQAR, RQA, RQB and RQ; Astralloy-V; and Oliver Formable 400 and Ultra-Tuff plate. Particularly preferred are plates identified as Hardox 400 and especially Hardox 500, respectively having the following reported properties:

	Hardox 400 (about)	Hardox 500 (about)
BHN hardness	360-440	450-560
yield strength	145 ksi	190 ksi
tensile strength	180 ksi	225 ksi
elongation (A5)	10%	8%
impact properties (Charpy V, longitudinal specimen)	18 ft. lbs. (at -40F)	18 ft. lbs. (at +14F)

Materials of higher hardness levels may be used.

The above illustrative metals are believed sufficient in fracture resistance, temper resistance and other properties enumerated above to be useful in making projections for use in the present invention. However, it is believed that a wide variety of other suitable metals is available and that persons skilled in metallurgy can adust metals composition and heat treatments applied to such other metals to achieve desired levels of weldability and durability to produce acceptable projections. For further guidance on effecting desired levels of hardness, fracture resistance, temper resitance and other beneficial properties in projections, see U.S. Patents 5,525,167 and 5,595,614 and other patents identified therein, the disclosures of all such patents being incorporated herein by reference in their entireties.

Projections of any acceptable thickness can be employed, for example about 1/2 to about 3 inches, frequently about 3/4 to about 2 and 1/4 inches, and in many instances about 1 to about 1 and ½ inches, most preferably about 1 and 1/4 inches for the applications with which the most experience has been acquired.

As the tips of projections are brought to bear on rock, sufficient force must be applied in order to penetrate the rock. Otherwise, the tips will only rub across the surface and no fracturing or “digging” will occur. More powerful equipment is able to supply more force per unit of tip area, which of course,

all other things remaining equal, is a function of thickness. Thus, in teeth for use on more powerful equipment, thicker metallic stock may be used in making the projections, and longer wear would be expected from thicker projections. However, the tips of narrower projections made from thinner metallic stock would be expected to enable a given piece of equipment to exert more force per unit area on the rock strata, and thus penetrate the strata more easily. Accordingly, it is beneficial to select projection thickness with the goal of effecting a balance between service life and ease of penetration. For applications in which ripping arms bearing one or two teeth comprising a total of two to four projections made from plate stock are employed on a large power shovel, such as a Caterpillar 385, a plate thickness of about 1.25 inches is presently considered optimum. It should be noted that it can be necessary or desirable to adjust characteristics other than projection thickness when preparing teeth for more and less powerful excavating machines.

Monolithic projections are preferred. A monolithic projection is composed substantially of a single thickness of a given portion of metallic stock.

The projections have “major surfaces”. In the case of projections formed from plate stock, the major surfaces are those portions of the projections that, if not surface-modified after cutting from the plate, were originally part of the largest surfaces of the plate stock, i.e., the top and bottom surfaces as distinguished from the edges; and it is for this reason that they are referred to as “major” surfaces. In the projections, these major surfaces are usually and preferably, but not necessarily, of larger area than any of the other surfaces, i.e., than the peripheral edges, of the projections. In the case of projections cut from bar stock that has approximately planar surfaces on opposite sides thereof that are approximately parallel, and preferably also in the case of projections cut from plate, the major surfaces are preferably those that are approximately parallel to the digging direction of the tooth. Approximately planar, as applied to bar stock, means at least nearly flat (i.e. essentially flat or, if its surface is arcuate, having a radius of at least 10, preferably at least 15 and more preferably at least 20 times its width) throughout at least 80, preferably at least 90 and more preferably at least 95 percent of its width. Approximately parallel, as applied to opposed

surfaces of a bar, means nearly parallel, i.e., with an angle of up to 20, more preferably less than 10, still more preferably less than 5 and most preferably zero degrees between those surfaces. Approximately parallel, as applied to the relationship between a digging direction and a surface of a projection, means that surface is more nearly parallel than perpendicular to that direction, more preferably at an angle to one another that is up to about 35 degrees, more preferably up to about 25 degrees, still more preferably up to about 15 degrees and most preferably about 9 degrees or less, including zero degrees.

Preferably, in the finished tooth, the abrasion resistance of each projection intermediate its major surfaces is at least a major fraction of its abrasion resistance at its major surfaces; preferably, the hardness of the projections intermediate their major surfaces is at least about 60, about 70, about 80, or above 90, percent of its major surface hardness.

One or more cut edges are present on projections cut from plate. Two or more edges may be cut from plate stock. However, one or more edges may correspond to the edge of a plate and thus will not be cut from the plate. Plate stock is preferably cut by an automatically guided gas jet cutter. For many of the available types of plates, their manufacturers recommend pre-heating prior to cutting and give specific recommendations as to temperature limits. These should be considered.

Projection edges may be of straight, curved, saw-tooth, stepped or other configuration(s), and the corners of the projections may be rounded, chamfered, or not. Preferably, there will be at least two edges having portions that converge to a tip. Convergence may be along straight, curved or other forms of axes to provide dagger shape, "hook" shape or any other suitable shape. Moreover, the convergence may be symmetrical or non-symmetrical, of uniform or non-uniform slope relative to the axis/axes and continuous or non-continuous. Where a projection is formed from bar stock, e.g. square bar stock, all of the convergence may be in portions of the edges closely adjacent the tip. Ranges of exemplary included angles of convergence between edges, e.g., throughout their length or only as the edges approach the tip, include about 10 to about 35 degrees, preferably

about 15 to about 30 degrees, more preferably about 17 to about 25 degrees, and still more preferably about 21±2 degrees. It is currently considered optimum/best for fracturing hard rock under heavy force to have the edges converge at about 21-1/4±1 degrees. One or both of the convergent edges may be chamfered, but these are preferably not chamfered.

As to the nature of the tip, it may be a sharp point if desired, but this is not necessary. While the tip may be squared off, a rounded tip is preferred. The tip may be cut as a segment of a circle with a radius of, e.g., about 0.1 to about 1 inch, preferably about 0.2 to about 0.7 inch, more preferably about 0.2 to about 0.4 inch and most preferably about 0.3 inch.

For an excavating machine capable of exerting a given force, larger and smaller tip radii respectively, all other factors remaining equal, result in the application of less and more fracturing force per unit area to rock strata. Thus, in selecting tip radii when designing teeth according to the invention, persons skilled in the art may wish to consider short radii for less powerful equipment and vice versa. While having a proper tip radius can be important when a tooth is first placed in service, it should be understood that such radius is likely to change or wear to a different shape as the tooth wears.

The shape of other edges and corners of the projections may be varied widely as desired, e.g., may be straight, curved and/or of other suitable shapes.

Tooth length may also vary widely as appropriate for digging and for providing enough overlap of projection and core to allow formation of welds of the requisite strength between them.

While the number of projections may be at least one per tooth, preferably two projections per tooth are preferred. There may be more than two projections per tooth. Where there are plural projections, it is preferred that there be divergence of one or more of these projections, for example divergence of the outer surface of a projection from a central axis of the

tooth or divergence of the outer surface of a projection from the outer surface of another projection.

When divergence is present, for example, in at least one projection of a tooth employed in trenching, moderate divergence assists the operator, when desired, in keeping the side of the trench vertical and in squaring off an intersection between a side and the bottom of the trench. Where vertical side walls and squared-off side-wall to bottom-wall intersections are not required or may be achieved in another way, at least one, e.g., all, of plural projection(s) in a tooth may be mounted with one or both of its/their major face(s) parallel to or convergent with the tooth axis. Where there is divergence, it may for example be about 1 to about 15, preferably about 6 to about 12, more preferably about 8 to about 10 and most preferably about 9, degrees from the tooth axis. Where the angle of divergence is expressed as the angle between major surfaces of two projections, the above maxima and minima of the above ranges are doubled. There can be an advantage in limiting the amount of divergence to no more than is needed to facilitate "squaring off"; in some tooth designs, careful control over the divergence angle will contribute to the strength of the tooth.

Providing divergence of one or more projections from the core axis, when such is provided, can be facilitated by securing a projection to a core side which, overall, is generally divergent from the core axis at the projection angle of divergence. Alternatively, one may secure a projection to a "land" representing a portion of the side of a core, the land being angled from the core central axis at the projection angle of divergence. Where a projection is not secured in the above manner, e.g., where the core has parallel sides, one or more shims may be placed between the inner surface of the projection and the adjacent surface of the core to orient the projection at the desired angle during fabrication, e.g., during welding.

In securing projections to cores, portions of projections may be secured in slots or grooves formed in cores or to longitudinal surface(s) of cores, which is preferred, or in any other way. A pair of projections is preferably secured to opposite sides of a core. However, one may also secure a first projection in a central groove at the front end of core, and secure second

and third projections to opposite sides of core. When at least one projection is secured to at least one longitudinal surface of the core, which is preferred, such projection(s) may and preferably do extend along at least a portion of the at least one longitudinal surface and a portion of said at least one projection extends past the front end of the core with the tip and at least a portion of the converging edges projecting beyond the front end of the core.

Although other securing methods may be employed, welding is preferred. One may employ any suitable welding techniques, which may include cleaning, e.g., by wire wheel or other means, and preheating the core and/or projection for any suitable time and temperature by any suitable heating method under any suitable atmosphere, e.g., to 150-200 degrees F. in air with a gas torch. One may employ any suitable welding process, flux, atmosphere, wire/rod type, temperature during welding, and any other details that might be considered useful. SMAW and GMAW are examples of suitable welding methods. In general, for welding excavator tooth projections to cores, it is considered good practice to form welds between the parts everywhere possible. Among the post-welding operations/steps to be considered are cool-down processing (time, temperature, atmosphere), quenching, wrapping the hot welded part in a welding blanket to inhibit cracking of welds. Plate manufacturers' recommendations should be considered.

A preferred welding procedure which has provided good results includes cleaning the surfaces to be welded by wire wheel, locating the projection(s) properly located on the core and tack welding them in place. The location of the plates is then checked. Now, 3/32" diameter T75 flux-core wire is applied to the joint where projection meets core. A preferred cover gas of 100% CO_2 is used with the T-75 wire. It is best to apply multiple passes in filling the joint. In addition, the temperature of the work-piece is held at 600 degrees F. or less. After the welding operation, the finished part is immediately wrapped in an insulating blanket for several hours to allow for slow cooling to ambient temperature, thus avoiding formation of cracks in the weld areas and heat-affected zone of the weld.

Teeth according to the invention comprise part of a connector, called the tooth connector portion, which is adapted to cooperate with another part of a connector, called the excavator connector portion, located on an excavator apparatus, as further described below. In this way, the tooth and excavator apparatus may be connected to one another in working relationship. The tooth connector portion is located in or on the core, preferably at (in, on or near) the rear end of the core and more preferably in or on the rearmost surface of the core. However, the tooth connector portion may be located in or on other surfaces of the core, e.g., its top surface, where such exists, its bottom surface, where such exists, a lateral surface(s), where such exists, or the front surface, where such exists.

The tooth connector portion includes at least one concave or convex connector surface, which may have circular configuration, may have any other suitable configuration and may be tapered or not tapered, but tapered surfaces are preferred for most applications. Viewed in transverse cross-section, the connector surface may for example appear at least partly circular, oval, triangular, square, rectangular, diamond-shaped, polygonal, of parallelogram shape, trapezoidal, a modification of any of the foregoing or a composite shape (combinations of any of the above, e.g. generally square but with rounded corners). The transverse cross-section may appear uniform or variable along most if not all of its length.

In longitudinal cross-section, the connector surface may be of any suitable shape, whether uniform or variable along its length, including not tapered or tapered, the latter being preferred.

The connector surface of the tooth connector portion is positioned and adapted to engage with and non-destructively disengage from at least one mating surface of an excavator apparatus.

Locking members may be provided to secure teeth to excavator apparatus. For examples of different locking members, both metallic, partly metallic and non-metallic, see U.S. Patents 6,047,487; 5,937,550; 5,638,621; 5,617,655; 5,579,594; 4,891,893; 5,653,048; 5,526,593; 6,079,132 and 6,247,255, which are incorporated herein by reference. It is not necessary

however that teeth according to the invention be held in fixed relation to their adapters; for reciprocation of projections or teeth by air or hydraulic drives, see U.S. Patent 5,495, 685.

For purposes of the present invention, an excavator apparatus is any excavating machine adapted to carry, in working position, one or more teeth constructed according to the invention, such as a mechanical or hydraulic power shovel, backhoe, trackhoe, dragline or shaft drill. In addition to such machines, excavator apparatus includes any digging attachment or combination of attachments adapted to be mounted on an excavating machine and to carry, in working position, one or more teeth constructed according to the invention, such as a blade, bucket, ripper arm, cutting chain, dredge cutterhead, quick-tool-connect/disconnect attachment or any suitable form of tooth adapter used with any of the foregoing.

Excavator apparatus usually comprises, as included or attached elements, one or more excavator connector portions that have one or more concave or convex surfaces adapted to mate with and form, in cooperation with one or more tooth connector portions of the core, at least a portion of a robust connector for securing a tooth or teeth to the excavator apparatus with sufficient strength to resist the loads imposed thereon in rock excavating service. The mating surface(s) on the excavator connector portions and on the tooth connector portions with which they cooperate preferably represent a nearly exact match, so that one fits snugly within the other in order to minimize relative movement of the surfaces after it/they is/are securely seated against or within one another. However, these surfaces need not in all circumstances be an exact match for one another or be in interfacial contact over their entire confronting areas. They need only abut one another over sufficient area to provide the required strength and load resistance.

In preferred applications of the invention, a major surface of at least one projection is maintained approximately perpendicular to an axis of an excavator apparatus. Approximately perpendicular means more nearly perpendicular to than parallel to an axis, which may for example be the axis of a pin or pivot, or an axis around which an identified part such as a ripper

arm pivots, or may be an edge of a part such as a bucket or blade. If one or more projections have their major surfaces angled vertically and/or horizontally (e.g., tilted and/or splayed) with respect to a plane that is perpendicular to such an axis, such angle(s) will be selected to limit resultant tearing forces on welds and/or other connections between the projections and their mountings (e.g., cores) as necessary to provide commercially acceptable resistance to breakage of those connections and of the projections themselves during operation, and more preferably to essentially prevent such breakage. Preferably, such angle(s) will be in the range of up to about 35 degrees, yet more preferably up to about 25 degrees, and most preferably up to about 15 degrees, including zero degrees. About 9 degrees is considered best. If the major surfaces are not planar, e.g., are of curved, corrugated or other cross-section, the angle of those surfaces relative to the axis may be judged on the basis of a sound approximation, for example, in the case of corrugation, the angle could possibly be measured in reference to a plane which includes the peaks of the corrugations; or in the case of a curved cross-section, the angle could possibly be measured in reference to a plane which includes the edges of the curved cross-section.

Benefits can be realized from preferred embodiments of the invention involving particular orientation of teeth relative to digging direction in excavator apparatus. In these embodiments, the teeth comprise one or more projections having a major surface/surfaces having a selected orientation relative one or more planes that is/are transverse to the excavator digging axis (e.g., the axis of rotation of an excavator arm relative to the excavator boom). Preferably, one or more projections is/are respectively in planes that are approximately perpendicular to the arm-boom axis. Still more preferably, each tooth comprises at least two projections that are in planes which diverge from one another at progressively greater distances in the direction of their tips. Preferably tooth connector portion and mating portion of the excavator apparatus are sufficiently symmetrical to permit rotation of the tooth and projections 180 degrees, so that direction of digging by the projections can be reversed and the wear on the projections can be equalized.

DETAILED DESCRIPTION OF DRAWINGS

Figures 1-2

Figures 1 and 2 illustrate a particularly preferred embodiment of an excavator tooth according to the present invention, having a metallic core with first and second projections 3 and 4. Were this core of circular transverse cross-section, which is an optional embodiment of the invention, the core could have a single, cylindrical, longitudinal surface. However, in the present figures, the core has four longitudinal surfaces, including top 5, bottom 6, first side 7 and opposite side 8. Its ends include front end 9 and rear end 10.

A connector portion 13 is located at rear end 10 of the core and more preferably in the rearmost surface of the core. Connector portion 13 includes a concave connector surface 14, which may be of circular or other configuration, positioned and adapted to engage with and non-destructively disengage from at least one mating surface (not shown) of an excavator apparatus (not shown).

In the present disclosure and claims, wherever reference is made to a concave or convex connector surface, whether in or on a core, or in or on an excavator apparatus, the singular form of the word "surface" includes the plural of this term. For example, connector surface 14, corresponding in shape with a truncated pyramid, comprises five surfaces, including those of four convergent inner walls 15 and of end wall 16.

Core rear end 10 also includes rearwardly projecting ears 17 with apertures 18 in them to receive a locking pin (not shown). These assist in fixing the excavator tooth to any form of excavator apparatus, such as an adaptor (not shown).

First projection 3 includes inner and outer major surfaces 20 and 21 while second projection 4 includes inner and outer major surfaces 22 and 23. In this preferred embodiment, inner major surfaces 20 and 22 have an angle of divergence 24 between them.

Convergent cut edges 25 and 26 of each of these major surfaces, which terminate in tip 27, define between them an angle of convergence 28. The projection back edges 29 blend into edges 25 and 26 through short arcs 30.

Welds 31 join the back edges 29 and portions 33 of the projections to portions 32 of the core. Portions 34 of the projections, not welded to the core, face one another and extend forward away from the core.

Exemplary dimensions for the embodiment just described, which has been found suitable for rock excavating service on power shovels, include an overall length, from the backs of the ears 17 to the tips 27 of projections 3 and 4 measuring 16 inches, a total projection length from back edges 29 to tips 27 of 9 inches, a convergence of projection cut edges 25 and 26 of 21.25 degrees, a radius for tips 27 of 0.3 inches, a radius of 0.5 inches for arcs 30, a maximum vertical spread of the projection cut edges 25 and 26, near their back edges 29 of 3.67 inches, a separation of the projection outer major surfaces 21 and 23 from one another, at their tips 27, of 10.75 inches, an angle of divergence of 18 degrees between the inner major surfaces 20 and 22 of the projections and a projection thickness of 1.25 inches where the projections have been cut from commercially available Hardox 500 plate stock.

Figure 3

This figure illustrates an excavator to 38 having a metallic core 39 of used material, in this case a used cast tooth from which the remnants of the worn digging points have been ground away. There are also first and second projections 40 and 41, similar to those of the preceding embodiment.

Core 39 comprises four longitudinal surfaces, including a top surface 42, a bottom surface (not shown), a first side 43 and an opposite side (not shown). This core also has front end 44 and rear end 45. Rear end 45 comprises tooth connector portion 48 including a concave connector surface at 46, similar to that of the preceding embodiment, as well as ears 50 and locking pin apertures 51.

Figure 4

In this embodiment, excavator tooth 55 has a first projection 56, in the foreground of the view, and a second projection 57 in the background. While the inner major surface of first projection 56 is not shown, its outer major surface 58 is in the foreground of the view. A portion of the inner major surface 59 of the second projection may be seen where a portion of the first projection has been broken out in the view. The outer major surface of the second projection is at the back of the part and thus it is not shown in this view.

The inner major surfaces of the projections may be parallel, convergent or preferably divergent, as viewed from above. Each projection has a lower convergent edge 60, upper convergent edge 61, tip 62 and back edge 63.

Unlike the previous embodiments, the core and tooth connector portions of the present embodiment are fabricated rather than cast. They include an upper inclined plate 67 and lower inclined plate 68 which are welded to and extend laterally between the inner major surfaces of projections 56 and 57.

Plates 67 and 68 are removed by a substantial distance 69 from projection tips 62. These two plates comprise convergent inner surfaces 70 and 71, representing a concave or female connector surface, e.g., pocket 72. Apertures 73, positioned in plates 67 and 68 intermediate the projection inner surfaces, are provided for insertion of a locking pin, as discussed below.

In this figure, an excavator apparatus is represented by a portion of an adaptor 74. It may for example be located on a digging implement or on any earth-working portion of an excavating machine. Here adaptor 74 includes a body 75 comprising a convex mating surface compatible with pocket 72. Body 75 also includes a bore 77 which is in registry with apertures 73 when the tooth is installed on excavator apparatus 74 and held in place with the aid of locking pin 78.

Figures 5-6

While former embodiments disclose fixing projections to outer surfaces of cores, one can construct useful excavator teeth in which one or more projections are mounted within one or more portions of a core. Figures 5 and 6 illustrate this.

This embodiment includes forked core 82 comprising main body 83 with forwardly projecting first and second arms 84 and 85, defining between them a cavity 86. Here, a single projection 87 having cut edges 88, tip 89 and back edge 90, the latter being defined by two angled portions 91 and 92, is secured in cavity 86. Such securing is accomplished by welds 93 between the back 94 of the cavity and the angled portions 91 and 92 of projection back edge.

Here, the tooth connector portion is, for example, a male member 99, preferably of truncated pyramidal shape. It extends rearwardly from the end 100 of core main body 83. The mating surface is a female member, for example a cavity 101 in an excavator apparatus 102, shown in phantom outline in figure 6.

A locking member, for example bolt 103, passes through matching holes 104 and 105 in tooth connector portion 99 and excavator apparatus 102. By engaging the tooth and a portion of the excavator apparatus, this bolt provides security for the connection between the tooth connector portion and its mating surface in the excavator apparatus.

Figures 7-9

Excavator teeth according to the invention can be used in virtually any kind of digging implement, for example above ripping arms illustrated in figures 7-9. In figure 7, an excavator tooth 107 having projections 108 is affixed to a ripping arm 106 with the aid of locking pin 109.

As shown in figure 8, a ripping arm, such as arm 106 of figure 7, may be secured to a base plate 110. Webs 111 projecting from the rear of base

plate 110 may be equipped with mounting pins 112 to engage with a quick-connect-disconnect appliance, by means of which this digging implement may be installed on an excavating machine, such as a power shovel or backhoe.

Figure 9 includes a base plate 110, webs 111 and mounting pins 112, similar to those of figure 8. However, here, two ripping arms 106 are secured to the base plate.

In figures 8 and 9, mounting pins 112 have axes 113. Major surfaces 114 of the projections 108 are approximately perpendicular to these axes.

Figure 10

This figure illustrates another type of digging implement on which excavator teeth of the present invention may be used. Here, the digging implement is a dredge cutter-head 117. It comprises central rotary shaft 118 having an axis of rotation 119 which is perpendicular to the plane in which this view is drawn. Spiral vanes 120, extending from shaft 118 have inner ends 121 and outer ends 122, support ring 123 being secured to the latter. A plurality of adapters 124 may be installed on ring 123 for mounting excavator teeth 125 with projections 126 whose major surfaces 127 are approximately perpendicular to axis 119.

Figures 11-12

Yet another type of digging implement in which the present invention is useful is excavator buckets. As will be shown, such buckets may have rectilinear or non-rectilinear cutting edges.

Bucket 131 of figure 11 includes sides 132, a back 133 and a bottom 134, having a substantially rectilinear cutting edge 135. Edge 135 defines a digging axis 136. Along this edge is distributed a series of adapters 137 on which excavator teeth 138 according to the invention is mounted. Major surfaces 139 of protrusions 140 in these teeth have their major surfaces positioned approximately perpendicular to digging axis 136.

The bucket 143 in figure 12 comprises sides 144, a back 145 and a bottom 146, having across its front an at least partly non-rectilinear cutting edge 147. Reference line 149, drawn through points at which the ends 148 of edge 147 intersect with sides 144, represents the digging axis of the bucket. Adapters 150, distributed across cutting edge 147, are provided for mounting a series of excavator teeth 151 on the bucket. To reduce clutter in the drawing, the teeth have been omitted from two of the five adapters. Each excavator tooth includes projections 152 having major surfaces 153 that are approximately perpendicular to digging axis 149.

Figure 13

Teeth fabricated according to the present invention can be utilized in a wide variety of excavating machines, one example of which is the rubber-tired backhoe machine illustrated schematically in figure 13. It includes body 157, and, at the front of the machine, a bucket 158, bucket arms 159 and bucket pivot 160. Rotational axis 161 of this bucket is perpendicular to the plane in which the figure is drawn and therefore is represented by a dot at the center of the pivot. A series of excavator teeth 162, only one being shown in this view, is distributed across the front edge of the bucket, for example in a manner similar to that shown in figure 11 or 12. These teeth have projections 163 with major surfaces 164 approximately perpendicular to axis 161.

Towards the rear of the machine is a boom 168 having a base pivot 169 upon which the boom may be raised and lowered. Upper pivot 170, having pivot axis 177, is a pivot point for excavator arm 171, which is mounted at the upper end of the boom. At the lower end of the arm is an end pivot 172 on which a digging implement, for example pivoting rock ripping implement 173, is mounted. Hydraulic boom lift cylinder 174, arm pivoting cylinder 175 and implement pivoting cylinder 176 are provided to raise and lower the boom, and move the arm and ripping implement back and forth. Excavator teeth according to the invention can also be used with backhoe units equipped with means to allow the boom to swivel from side to side around a vertical axis, but that feature has been omitted from the present drawings to simplify them.

At the center of end pivot 172 is a pivoting axis 181 about which ripping implement 173 pivots when digging through rocky strata. Excavator teeth 178, made according to the present invention, have projections 179. Their major surfaces 180 are approximately perpendicular to axes 177 and 181.

Figure 14

Excavator teeth according to the invention have demonstrated their durability in service on the buckets of large power shovels, such as that shown schematically in figure 14. Typical machines of this type move on crawler tracks 185 and include a body 186, boom 187, boom base pivot 188, boom lift cylinder 189, arm 190, boom-arm pivot 191, arm pivoting cylinder 192, implement 193, in this case a rock ripping arm, implement pivot 194 and implement pivoting cylinder 195. Pivots 188, 191 and 194 include, respectively, pivoting axis 200 about which the boom swings up and down, pivoting axis 201 about which the arm swings in and out and pivoting axis 202 about which the implement swings back and forth.

Implement 193 is equipped with excavator teeth 203 according to the invention. They include projections 204, the major surfaces 205 of which are approximately perpendicular to axes 200, 201 and 202.

Figures 15-16

Another example of many types of excavating machines on which the excavator teeth of the present invention may be used is draglines, an example of which is shown schematically in figures 15-16. As is usual in such equipment, this embodiment includes main boom 210 having base pivot 211, overhead cable system 212 to support -- and winch cable system 213 to draw -- bucket 214, all as shown in figure 15.

Base pivot 211 has a pivoting axis 215. As shown in greater detail in figure 16, bucket 214 has excavator teeth according to the present invention with projections 217. These projections have major surfaces at least some and preferably all of which that are approximately perpendicular to axis 215.

The present disclosure has discussed and illustrated a number, but certainly not all, of the different ways in which the present invention may be practiced. Accordingly, the following claims are intended to cover all the embodiments falling within their literal scope, whether specifically disclose herein or not, and all equivalents thereof.

DEFINITIONS

Excavate, excavating, excavation, excavator, digging, ripping and related terms employed herein are intended to be construed broadly to include all forms of earth moving whether they result in formation of a cavity in the earth or not. For example, these terms include not only trenching, dredging and formation of other types of open cavities in the earth or in the earthen, including rocky, sub-soil of a body of water, but also ripping, scraping, stripping, grading, leveling and other forms of earth moving that disturb earth, as distinguished from merely carrying it from one place to another. In this context, earth includes not only soil, but also frozen soil, gravel and layers at or below the earth's surface comprising mostly mineral matter and which may be essentially all rock, and may include solid rock strata, which represents a particularly useful application of the invention.

What is claimed is: